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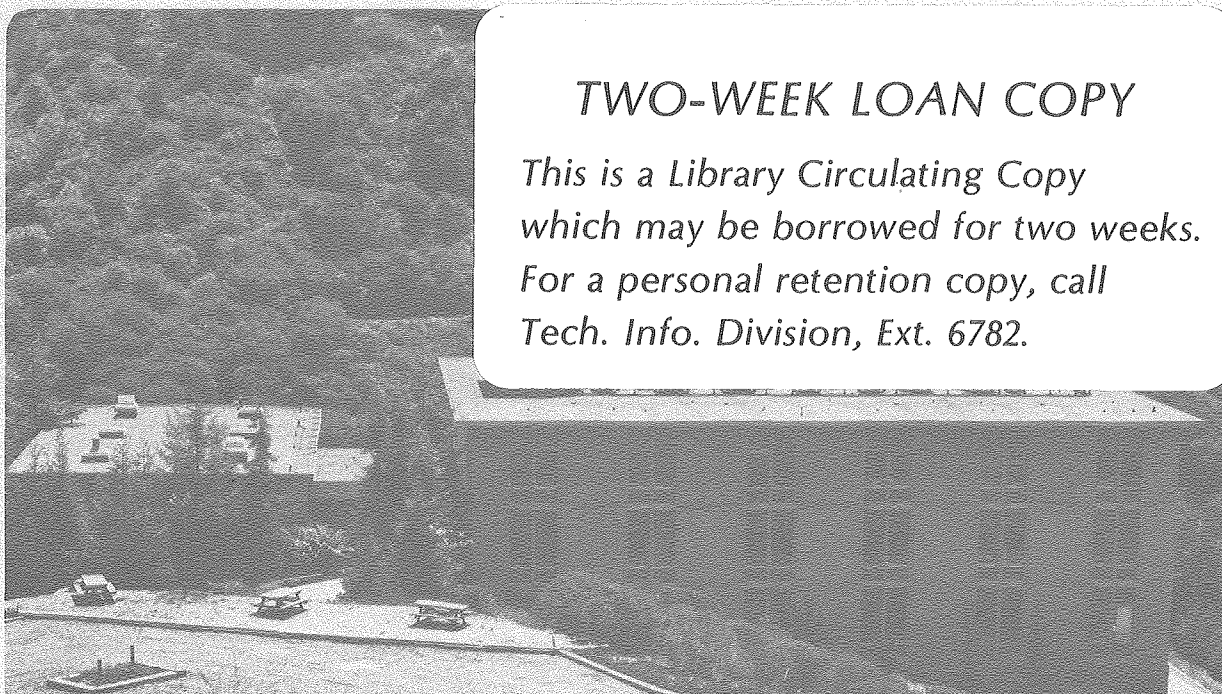
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OVERLAY COATINGS FOR GAS TURBINE AIRFOILS^{*}

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ABSTRACT

The present understanding of the degradation modes associated with gas turbine operation under a variety of conditions is reviewed as a preliminary to defining the needs of protective airfoil coatings and processing techniques. These requirements and present coating procedures are briefly described as an introduction to the need for overlay type coatings in general and electron beam (EB) evaporation processed coatings in particular. A discussion of the features of production EB coaters is followed by a detailed description of the individual coating processing steps involved. While most are identical to other coating procedures, a few are significantly different and are discussed in detail. A review of the understanding of current overlay coating compositions and their use-experience is followed by a brief discussion of future directions in overlay coating processing and compositions including electron beam-physical vapor deposition (EB-PVD) applied ceramics.

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INTRODUCTION

It is very important in any discussion of the technology of the application of protective coatings to gas turbine airfoils to have some understanding of the requirements, both of the coated components and of the compositions and processes necessary to withstand these conditions.

Turbine airfoils are one of the most difficult and demanding engineering design and materials challenges today. While their function is rather simple, that of changing air flow direction (vanes) and converting pressure differences into rotary motions (blades), the environment in which they operate is such that they are often the life limiting components of the turbine. As a result, major research efforts are expended in developing new turbine materials, coatings and processes, both to extend the useful lifetime of existing components and to improve their capabilities to allow use under even more severe conditions. It is important to note here, that an airfoil is an elegant combination of a design, a substrate material, its manufacturing process, a coating and its application procedure. It is an engineering system and as a result, in the specification of a protective coating, the selection and use of an application process and the allowable rework procedures are intimately tied into the overall turbine design philosophy.

Airfoils come in a large range of sizes and shapes depending upon the usage requirements for the turbine, its power level and mode of operation. They are produced from a variety of materials by a number of sophisticated manufacturing processes. Some typical airfoils requiring protective coatings are shown in Figure (1). Airfoil material

and manufacturing procedure can influence the selection of the coating type and composition. For example, the cobalt base superalloys, often used for higher temperature and lower stressed components such as vanes, do not contain aluminum as an alloying element and thus are limited in the aluminide coating thicknesses that can be applied without spallation. Superalloy compositions, carefully tailored to be free from the formation of potentially embrittling phases, such as sigma, can be destabilized by coating interdiffusion.⁽¹⁾ The use of structural strengtheners such as the submicron oxides in the oxide dispersion strengthened (ODS) alloys and the carbides in some directionally solidified (DS) eutectic alloys can also affect coating selection.⁽²⁾

The need for the use of protective coatings has been well documented.⁽³⁾ However, it may be instructive prior to the description of an advanced coating system to re-emphasize a few key factors which influence the selection of both coating composition and process.

As demands for improved gas turbine performance and efficiencies continued, substrate alloy research programs resulted in the development of higher strength alloys, and the processes to make them, for use in thinner sections and/or at high temperatures. Almost invariably this was at the expense of inherent alloy oxidation/hot corrosion resistance and later on, even coatability. The result often was the use of a new alloy with lower surface stability as a direct replacement with some loss of durability. However, because of the higher strength of the alloy, it was inevitably used at a higher temperature with an even greater sacrifice in uncoated lifetime. In the 1960's protective coatings (in general the aluminides) were used to extend the lifetimes

of uncoated airfoils from, for example, 8,000 hours to 12,000 hours, while in the 1970's protective coatings (in general the MCrAlY overlays) were necessary to meet even minimum engine testing and performance demonstration requirements.

The protection of gas turbine systems at high temperatures is effected in the same manner as the protection of other alloys in other corrosion environments. Namely, a stable protective (passive) film, invariably an oxide, is induced to form on the surface of the component. The stability of a number of typical oxide films is shown in Figure (2). The advantages of Cr_2O_3 over NiO or CoO are obvious and could be predicted by the success of the many Cr_2O_3 forming systems in use today. A problem with Cr_2O_3 not shown in this data is the volatility of CrO_3 at temperatures above $\sim 1,000^\circ\text{C}$ in rapidly flowing air such as turbine combustion gases.⁽⁴⁾ Based on these findings, it is not surprising that most gas turbine airfoil coating systems depend upon the formation of an Al_2O_3 layer or Cr_2O_3 if used at lower temperatures (for severe low temperature hot corrosion with vanadium and other 'bad' fuels, renewed interest has been centered on SiO_2 or mixed oxide systems forming SiO_2 as one component).

The basis for modern coating technology is the enrichment of a substrate alloy surface layer by a diffusion or overlay process such that, in service, a suitable protective oxide layer will be formed. Thus, this 'coating' does not furnish the direct protection, but provides for the formation of the protective oxide layer. Oxidation degradation of these systems usually involves the cyclic loss of this layer by thermally induced spallation and its subsequent reformation. At some

point in service lifetime, an insufficient amount (activity) of the critical element, e.g., aluminum, is available for the desired oxide to form and a less protective layer, incorporating critical substrate alloying materials is formed. Rapid weight loss, substrate attack and mechanical property degradation occur at this point and component removal must be promptly initiated if refurbishment is desired.

In the presence of air and/or fuel derived contaminants such as sea salt and heavy metals, molten turbine deposits can occur which greatly accelerate the oxidation degradation process.⁽⁵⁾ Often the effect of these deposits is to interfere with the protective oxide layer, either its formation or stability. Most present theories attribute the attack to fluxing of the protective oxide, and the accelerated degradation is referred to as 'hot' corrosion. Because of the necessity for the presence of a molten flux (often a mixture based on Na_2SO_4) the attack can be more aggressive at the low to intermediate temperatures (600 - 850°C). The presence of erosive particles in the gas stream can also serve to increase the rate of removal of the oxide particularly in the presence of a corrodant. This is thought to be primarily a problem with land based turbines and with the use of low grade fuels.

In recent years, the careful documentation of the various service coating degradation morphologies has greatly aided in the understanding of the attack mechanisms and in the identification and development of appropriate protective coating systems.⁽⁵⁾

One additional potential coating related mode of failure should also be mentioned: mechanical degradation, such as thermal fatigue and creep rupture. With today's structurally complex substrate alloys,

the presence of a coating and the effects of the coating application process on the substrate must be considered in the development and specification of a coating system. In addition to the compositional and processing effects of the presence of a coating, the physical effects (the behavior of the systems as a composite structure) are only recently being given proper attention in the literature.⁽⁶⁾

PROTECTIVE COATINGS

As can be seen from the other papers of this symposium, a variety of techniques are presently available for the application of coatings and it is not surprising, considering the importance of the problem, that many, if not all, are being used or have been considered for the protection of materials in the gas turbine. As detailed elsewhere,^(3,4) present day coating techniques can be divided into essentially three types as shown in Table (I). We will briefly review some of the salient features, advantages, and limitations of these various coatings.

The most widely used coating system for turbine airfoils is the chemical vapor deposition (CVD) aluminizing process, either in the pack (pack aluminizing) or out of the pack. It was introduced in the late 1950's as the use temperature and strength requirements of the second generation gas turbines necessitated the selection of lower chromium level superalloys. At these increased temperatures, even the existing alloys were incapable of providing the necessary durability and lifetimes.

The aluminizing process and the resulting structures are now well understood and explainable.⁽⁷⁾ It is important to note that this in-depth understanding is probably one reason for the widespread and successful use of these coatings and an equivalent level of understanding is necessary in the other coating technologies for their optimum utilization.

The structure of a typical three zone high activity (inward type) aluminide coating on a nickel base superalloy is shown in Figure (3) together with a list of some of its features and limitations. Because the coating depends upon the substrate for all elements but the aluminum, the composition and hence, properties of the coating depend, to a large extent, upon the particular alloy used. As the substrate alloys have been strengthened, they contain less chromium, more carbide phases and second phase reinforcement such as TaC or oxide dispersions, the quality of the coatings and their protectivity have decreased. Therefore, it is not surprising that the aluminides were not able to provide the required protectivity for advanced gas turbines being produced in the late 1960's, or many commercial, marine and industrial turbines being produced in the 1970's. In addition to the limitation of inadequate protectivity, another problem with the aluminides arose with the use of thin wall airfoils and air cooling. High surface tensile strains produced by rapid cooling and cooling hole stress raisers resulted in thermal fatigue cracking of these coatings. The NiAl, CoAl type aluminides have a high brittle-to-ductile transition temperature with corresponding low ductilities, less than 0.5 percent at the temperatures where maximum tensile stresses can occur.⁽⁸⁾ Premature cracking of critical airfoils can result. Attempts to lower the transition

temperature by the reduction in coating aluminum content are limited by diffusional considerations and the required coating lifetimes.

In the mid-1960's the ability to produce a coating tailored for the specific environmental and mechanical conditions, independent of the substrate composition and structure, was required. Attempts to modify the composition of the aluminide coatings by means of pre-surface treatment such as chromizing or noble metal plating have been partially successful for certain applications. However, because of limitations such as the solubility of chromium in the NiAl phase, the effect of a prior chromizing treatment on substrate stability and the limited ductility of the NiAl and noble metal intermetallic phase, for many applications, a more ductile and totally substrate independent coating was still required. Such coatings have been termed an overlay type and totally depend for their composition on the deposition process as opposed to the previously discussed diffusion type coatings. Figure (4) shows the microstructure of an EB-PVD applied CoCrAlY overlay coating that will be discussed below. For the deposition of protective overlay coating compositions a number of application techniques are possible as listed in Table (II).

During the development of overlay composition and processes in the 1960's the electron beam evaporation physical vapor deposition process emerged as the most suitable, and a strong production technology has developed over the past ten years. These developments resulted from the joint efforts of Pratt & Whitney Aircraft, East Hartford, Connecticut and Airco Temescal in Berkeley, California. Recent increases in the use of overlay coatings for the expanding number

of commercial and military aircraft gas turbine engines as well as marine and land base propulsion and power generating turbines has accelerated the interest in overlay processing techniques particularly sputtering and plasma spray. However, the EB-PVD process is presently the primary production technique and will be the basis for the following discussion.

THE OVERLAY COATER

At present there are at least two suppliers of production EB-PVD airfoil coaters and while there are some significant design differences between them (which are not covered in this paper) the basic functions are essentially the same. Figure (5) is a schematic drawing of a multi load lock coater showing the basic components and features.

Like the gas turbine engine, the EB-PVD coater is simple in theory, but more complex in actual operation. In a suitable vacuum environment, generally 10^{-4} to 10^{-6} Torr an electron beam is impinged on a water-cooled copper hearth containing the material to be evaporated. A continuous ingot feeding system is used to maintain the molten pool height and composition at an equilibrium condition. Evaporation rate and coating thickness build-up are often monitored and controlled by a laser pool height indicator with suitable feedback to an ingot feed system. The shape and size of the ingot can vary, but is dictated primarily by present vacuum induction melting capabilities and the properties of these relatively high aluminum content coating alloys. They usually consist of 5 to 10 cm diameter bar stock.

Due to the shape and distribution of the elements in the vapor cloud, the ingot composition can be different from the specified airfoil composition.⁽⁹⁾ In addition, the composition of the molten pool is different from both. However, under equilibrium conditions, which are rapidly established at pool temperatures of 1,600 - 1,900°C, the composition of the vapor out of the pool must be equal to the composition of the ingot being fed into the pool. The size and shape of the crucible is selected to maximize deposition and thermal efficiency and, in many coaters, the shape and density of the electron beam is controlled, producing a specific pool temperature profile with corresponding vapor composition and density distribution.⁽¹⁰⁾

The EB power requirements vary with the coater size, the number of airfoils that can be properly positioned in the vapor cloud and the desired rate of coating deposition. Presently, coater power supplies are in the 100 - 200 KW range. While early studies for other PVD systems indicated that increasing evaporation rates (which are proportional to deposition rates) resulted in a reduced quality coating structure, recent studies on MCrAlY airfoil coatings revealed the opposite. The quality of the deposited coating increased as the evaporation/deposition rate was increased.⁽¹¹⁾ Deposition rates exceeding 25 $\mu\text{m}/\text{min}$ are common as opposed to high rate sputtering techniques where 50 $\mu\text{m}/\text{hour}$ are still being sought.⁽¹²⁾ The effect of these high deposition rates coupled with advanced part handling and tooling, discussed below, is coater throughput exceeding 500 standard size parts in an eight hour shift.

The results of these and other process and equipment improvements over the past ten years has been the reduction in the coating price for a typical size airfoil, e.g., JT9D first blade. It has been estimated that the price for a fully processed component in quantities of 5 - 10,000 per month has decreased from ~\$85 in the early 1970's to ~\$40 in 1980.⁽¹³⁾ Other coater features such as preheating and oversource heating capabilities follow good vacuum furnace design criteria and will be discussed below, where appropriate, in conjunction with processing details.

THE OVERLAY COATING PROCESS

Although in this paper and elsewhere most of the attention is directed towards the actual deposition of the overlay coating on an airfoil, a significant part of the process, time, expense and manpower can occur during the pre- and post-coating processing steps. A typical list of the processing sequence is shown in Table (III). As is inferred, the actual coating deposition steps can be as little as 40 - 50 percent of the total 'coating' cycle. Many of the individual steps are straight forward and are common to most other coating procedures discussed in this lecture series and elsewhere and need only be listed. Examples include inspection, post coating heat treatment and shipping. However, certain steps are critical and unique to the PVD process and will be described in more detail below.

Surface Preparation. Surface cleaning operations provide the standard function of removing scale, oxides and dirt from previous operations and can vary with the history of the part and substrate

alloy. In general, however, they involve an abrasive blast or tumbling operation(s) followed by suitable cleaning to remove embedded grit. But, unlike some coating techniques, production of a given level of surface roughness, often greater than 100 μ in, is not required for adherence and, in fact, may be detrimental in its effect upon columnar coating growth as discussed below.

Coating Masking. Because the EB-PVD coating process is essentially line-of-sight; procedures necessary to protect 'no-coat' areas on specification drawings can be relatively simple. However, it must be remembered that the masked part can undergo a thermal cycle to $1,000^{\circ}\text{C}$ for periods of 5 - 30 min. Masking is often best accomplished by proper part holder design and final machining sequencing. Additional masking can be required for areas such as blade tip shrouds and for this purpose mechanical and/or chemical barriers are used. As in the pack cementation process, specific systems used are often proprietary and represent a compromise between ease of the application, effectiveness, attack of substrate and ease of removal.

Pre-Coater Processing. In the coating process, properly prepared airfoils are loaded into tooling which serve the dual function of holding and maneuvering the part in the vapor cloud and masking or shielding specified coating-free areas from the essentially line-of-sight vapor. In most instances, the tooling design and construction is proprietary and unique for specific airfoil shape and coating requirements. Recently disclosed patents detail a modified planetary system which allows multiple parts to be supported from one shaft, independently rotated and indexed in the coating vapor to obtain the required thickness

profile.^(14,15) The use of such multiple part tooling together with multiple shaft coaters and increased evaporation rates has substantially increased coater throughput from less than 100 to over 500 parts per shift.

Coating Deposition. The PVD coating of airfoils differs in two significant ways from other coating processes and techniques. First, the substrate to be coated is pre-heated in vacuum $\sim 1,000^{\circ}\text{C}$ prior to exposure to the coating vapor⁽¹⁶⁾. During coating deposition, the substrate is maintained at temperature by a combination of pool radiation, heat of condensation and an additional over source heater. The use of pre-heating and a heated substrate during coating results in the deposition of an adherent coating with some minimal amount of substrate-coating interdiffusion occurring during the coating cycle. Coating spallation, a problem with many coating processes and systems, is, thus, not a problem for properly cleaned substrates. In some EB-PVD coating work, where argon gas is used to promote randomization of the essentially line-of-sight evaporation, sufficient cooling of the vapor can occur with the result that decreased structural quality and poor adherence is seen. For these conditions the use of a substrate bias, so-called ion-plating can be used to provide the additional energy necessary for the required surface atom mobility and interdiffusion.⁽¹⁷⁾ The optimum temperature depends upon the system involved and can range from $800 - 1,100^{\circ}\text{C}$. A finer as-deposited structure results at the lower deposition temperature and a coarse grain structure and more substrate interdiffusion at the higher temperatures. In addition, some surface re-evaporation can occur at the higher temperatures.

For the deposition of MCrAlYs on typical superalloy substrates, 1,000°C is often found to be a convenient temperature and is compatible with most alloy heat treatments as well.

A second feature of the EB-PVD overlay coating process is the rotation of the substrate during deposition. Coatings deposited on a rotated substrate often have an as-deposited columnar grain structure with unbonded interfaces known as 'leaders.' These structures have been shown to result from the shadowing by the individual coatings growing in a preferred direction.^(18,19) Increasing deposition temperature which increases surface diffusivity reduces the density of these leaders, as does increasing the angle between the surface to be coated and the vapor flux.⁽¹²⁾

Post-Coating Processing - Peening. It has been shown that a post-coating surface peening process (often using ~200 µm glass beads) followed by a heat treatment results in a complete closure of these leaders and most EB-PVD applied coatings operations including a peening operation. It could be noted that this peening operation also serves to remove chemical masking materials and to clean up areas of coating overspray. Peening has little affect on as-deposited surface smoothness, possibly some slight improvement to ~40-60 µin. Final coated airfoil surface smoothness is an important factor in turbine efficiency and could involve additional processing steps if as-deposited coatings were too rough, e.g., >~100 µin.

Recoating. As for other coatings a procedure is necessary to allow removal of the overlay coating once applied. This need can result from the generally 1 - 5 percent coating rejects identified

during inspection or from service operated parts. For service parts, because of the expense of complex airfoils, it is desirable to remove the component prior to extensive attack of the substrates. The typical procedure involves stripping the coating, reworking the component and then recoating and subsequent return to service. Presently, a considerable research and development effort is being expended in studying airfoil repair and refurbishment techniques including effects of welding, hot isostatic pressing and reheat treatment. This effort and the use of reworked parts is predicted to expand rapidly. Current EB-PVD coating removal techniques require acid dissolution of compositionally different coating alloy from the substrate. For many overlay coatings the techniques are similar if not identical to those used for the aluminide coating. Again, some proprietary processes and techniques prevail. One difference between the aluminide and the overlay coating is that since the aluminide involves the interaction with the substrate for its formation, stripping results in the removal of this substrate and greater dimensional changes.

As the compositions of the overlays approach that of the substrate, in particular for aluminum, and/or the substrate because more structurally complex and less corrosion resistant, some problems of removal of the coating without selective attack of the substrate can be expected and techniques such as substrate masking have to be employed. In general, the processing procedures for the EB-PVD applied coatings are little different from other coating procedures. The development of an understanding of metallurgical features of these coatings has allowed a

relatively simple transition from the research laboratory to the production floor.

THE OVERLAY COATINGS - MCrAlY'S

Following the discussions of the techniques and procedures employed in the EB-PVD overlay coating of airfoils, it may be of interest to review the availability and selection of overlay compositions.

At present, a discussion of these compositions is a discussion of the MCrAlY (M = Fe, Co and/or Ni) coatings.⁽³⁾ Early interest focused on several cobalt base CoCrAlYs of relatively similar Cr, Al and Y levels and these have been the primary compositions used in production. The reasons for the selection of a specific composition has been discussed in the literature in some detail and involves many considerations and trade-offs as occur in any materials selection procedure for a critical component such as a turbine airfoil. However, increasing demand as previously noted has resulted in the need to develop additional compositions for more specific applications such as extended operation in a marine environment or high temperature operation with high thermal fatigue strains on controlled solidification alloys in advanced military environments. Improvements in the process have also resulted in a decrease in the compositional range that can be specified and controlled. The result is that where one or two compositions were in use ten years ago, today, over thirty production and experimental compositions are in use or under active development. It should be cautioned that, as yet, many of these specific coatings are proprietary.

Some factors involved in the selection and level of the MCrAlY are elements and are briefly reviewed below. Chromium is present primarily to provide oxidation and hot corrosion resistance of the coating. Because of the potential scarcity and cost, the trend is to use these critical elements in the small volume coating and not the larger volume substrate. Also, the detrimental effects of higher chromium levels on mechanical properties of superalloys are not a concern in the essentially non-load carrying coatings. However, the use of too high a level in the coating could affect substrate stability. The presence of chromium has the effect of increasing the aluminum activity of these coatings such that protective Al_2O_3 can be formed to lower aluminum levels. This allows the use of compositions with lower aluminum contents and hence improved mechanical properties.

Aluminum is present to form Al_2O_3 as previously discussed. While higher levels result in longer lifetimes (at least under oxidizing conditions), excessive brittleness and a higher temperature ductile-brittle transition temperature can result. The trend is to use aluminum levels below 12 percent and coatings in the 5 - 10 percent range are presently being explored.

The key to success of most overlay coating compositions is the presence (and possibly location) of an oxygen active element such as yttrium. In a not completely defined manner, these elements promote adherence of the Al_2O_3 layer during extended cyclic exposures, resulting in an increase in coating protectivity at lower aluminum levels. The MCrAlY's with ~12 percent Al are significantly more

protective than the aluminides with ~30 percent Al. The ductilities of the lower aluminum MCrAlY's are also a significant feature of the active elements containing coatings as has been documented.

The continual demand for improvements in overlay coating performance has resulted in a number of active coating development efforts being initiated during the past several years. It is predicted that results of these programs will result in the use of even more complex coating compositions and the introduction of structural as well as compositional control.

SERVICE EXPERIENCE

EB-PVD coatings have been in service for approximately ten years on FT4, JT9D and other gas turbines, and their use continues to expand and increase. Because of proprietary positions and for competitive reasons, little specific information on data is available in print, except for the reported increasing overhaul time and performance for the turbines using overlay coatings. It was recently reported in Aviation Week,⁽²⁰⁾ that the JT10D would incorporate the most advanced single crystal turbine airfoil and a NiCoCrAlY, EB-PVD overlay coating. Likewise, the newly designed F-100 first turbine blade produced in the Pratt & Whitney Aircraft foundry will continue this trend towards advanced alloy and coating technology such as EB-PVD.

NEW DIRECTIONS IN EB-PVD

Due to these trends towards increased coating complexity, coupled with the concern for the ability of an evaporation type process to produce deposits containing elements with greatly varying vapor pressure, recent studies have been directed towards better defining the capabilities of the EB-PVD process. Although studies are continuing, it has been shown that five and six element MCrAlY coating compositions containing elements with varying vapor pressures could be produced,⁽²¹⁾ e.g., CoCrAl coating containing the active element addition, hafnium, or hafnium and yttrium was deposited using a production coater. There has been considerable interest in the potential beneficial effects of hafnium coating additions. In addition, with the use of a multi source evaporation unit, a coating with composition graded from the substrate to the surface can be produced as well as a two phase structure containing an oxide dispersion.

Further investigation has shown that ceramics as well as metallic coating compositions can be deposited using the EB-PVD process.⁽²²⁾ For example, coatings varying in thickness from 25 μm to 250 μm have been deposited with stabilized cubic zirconia structures and growth morphologies portending improved thermal fatigue resistance. The use of a ceramic coating on a metal substrate offers the tantalizing combination of the ceramics surface stability and thermal barrier properties on a tough, high strength superalloy substrate. In the case of ceramic coatings, the control of the structure is found to be possibly as important as the composition itself in promoting resistance to thermal fatigue induced spallation. Activity in this

area of ceramic thermal barrier coatings is predicted to increase as rig and engine testing continues to report favorable results.

SUMMARY

The need for the use of protective coatings will continue to increase as our quest for greater energy efficiency and more diversified fuel sources expands. Overlay coatings and composite systems will be needed to meet these requirements in a cost effective manner consistent with materials availability. These needs have spurred interest and activity in the overlay coating processing area in general and in EB-PVD techniques in particular.

Results of recent studies show that the capabilities of the EB-PVD processes are much broader than previously detailed in the literature. Complex metallic coatings containing a number of elements including those with widely varying vapor pressures can be readily deposited from a single evaporation source. By using a dual source, metallic coatings can be produced which contain a composition gradient in at least one element. In addition, a metallic coating containing a ceramic can be produced. With a single source, ceramic compositions can be evaporated in useful thicknesses and times using existing production coating equipment and procedures. The ceramic coating structures contain columnarly orientated boundaries and pores, whose size and density can be controlled. The ability to produce such structures offers the promise of significant improvement in the mechanical properties of this important new class of coating materials.

Greater interest and activity is predicted in the future.

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22. D. H. Boone, S. Shen and J. W. Fairbanks, "Advanced Gas Turbine Coatings for Minimally Processed Coal Derived Liquid Fuels," presented at the Conference on Advanced Materials for Alternate Fuel Capable Directly Heat Engines, July 1979, Castine, Maine, published in the proceedings.

Table I. Potential gas turbine airfoil coating types.

Diffusion Coatings:-

Aluminum, the aluminides
Chromium, chromizing treatments
Silicon, the silicides

Duplex Coatings:-

A layer plus a diffusion coating,
e.g., a noble metal layer plus
aluminizing or chromizing plus
aluminizing

Overlay Coatings:-

Coating composition independent
of substrate

Table II. Potential protective overlay coating application processes.

Physical Vapor Deposition (PVD)

- A) Electron beam evaporation and variations such as ion plating
- B) Sputtering

Thermal Spraying

- A) Plasma (PS)
- B) Shielded plasma
- C) Low pressure plasma (LPPS)

Chemical Vapor Deposition (CVD)

Fused Salt Electrolysis

Laser Fusion

Slurry Reaction Sintering

Table III. List of EB-PVD processing steps.

Receiving
Inspection and Batching
Surface Preparation:-
Degreasing
Grit Blasting
Vapor Honing
Weighing
(if used as thickness and process control)
Loading Into Fixtures and Masking
Coating Cycle
Pre-Heating
Coating Deposition
Cooling
Removal from Fixtures
Weighing
Overspray Removal
Peening
Diffusion Heat-Treatment
(often substrate alloy solution treatment)
Aging Heat-Treatment
(if specified)
Inspection and Documentation
Shipment
Reworking - if applicable
(stripping and re-cycling through appropriate process)

Information: Overlay Coatings for Gas Turbine Airfoils

Published in AGARD [Advisory Group for Aerospace Research and Development]

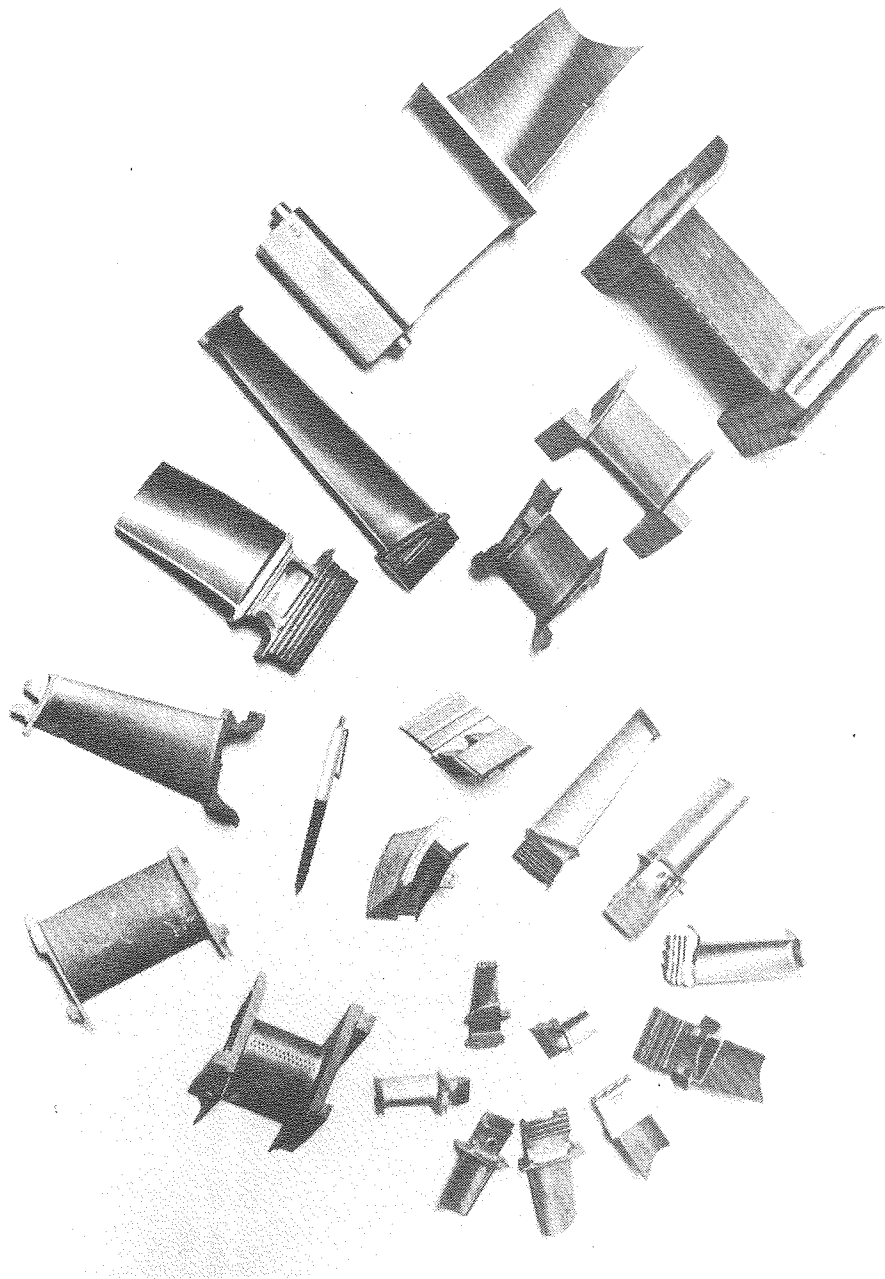
Lecture Series Publication LS No. 106 "Materials Coating Techniques"

& presented at the following lectures:

27-28 March, Lisbon, Portugal

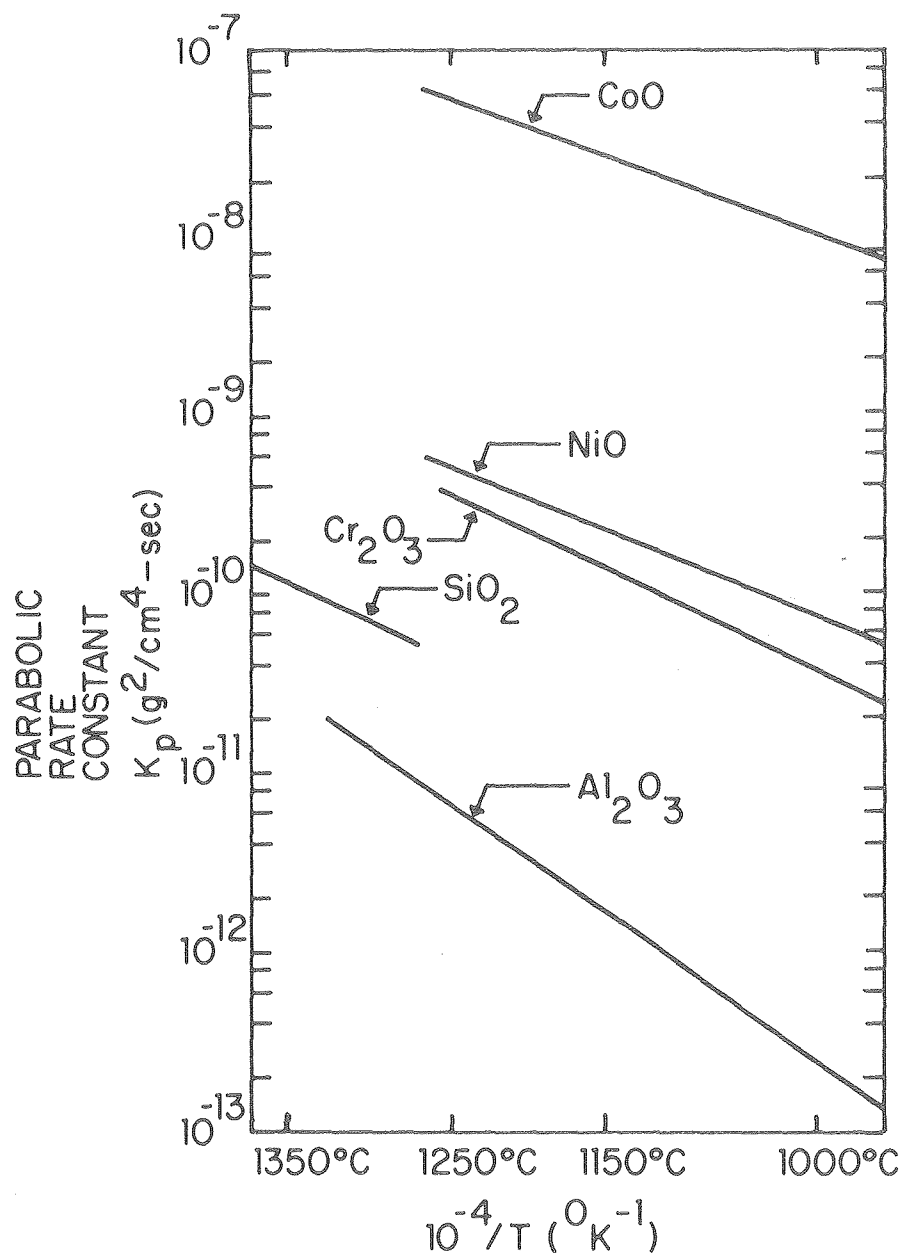
31-1 April, Athens, Greece

3-4 April, Ankara, Turkey



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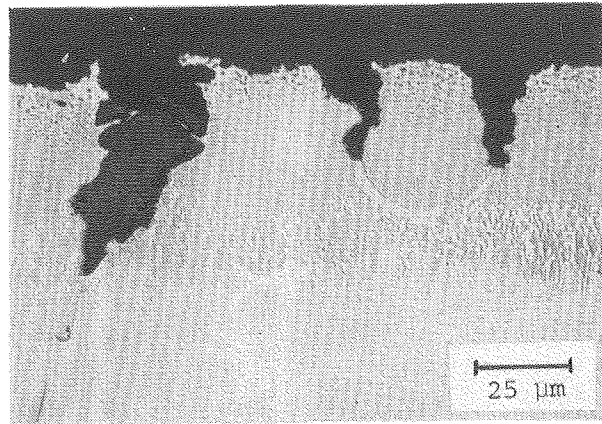
Fig. 1. Typical Gas Turbine Airfoil Geometries that Require Protective Coating Showing Requirements for Advanced Coating Processing Techniques.



XBL 802-8279

Fig. 2. Plot of Parabolic Rate Constant versus $1/T$ for various metals forming CoO, NiO, Cr₂O₃, SiO₂ and Al₂O₃ layers showing the diffusional stability of Al₂O₃ forming system (5).

ALUMINIDE COATINGS



XBB 802-2597

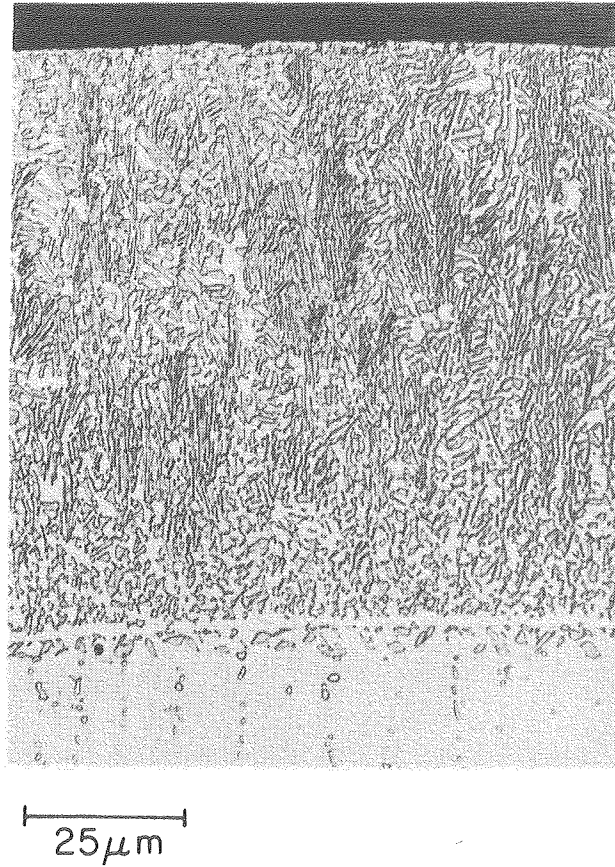
ADVANTAGES

Simple Process
Inexpensive
Non Line-of-sight
Good Oxidation Resistant

LIMITATIONS

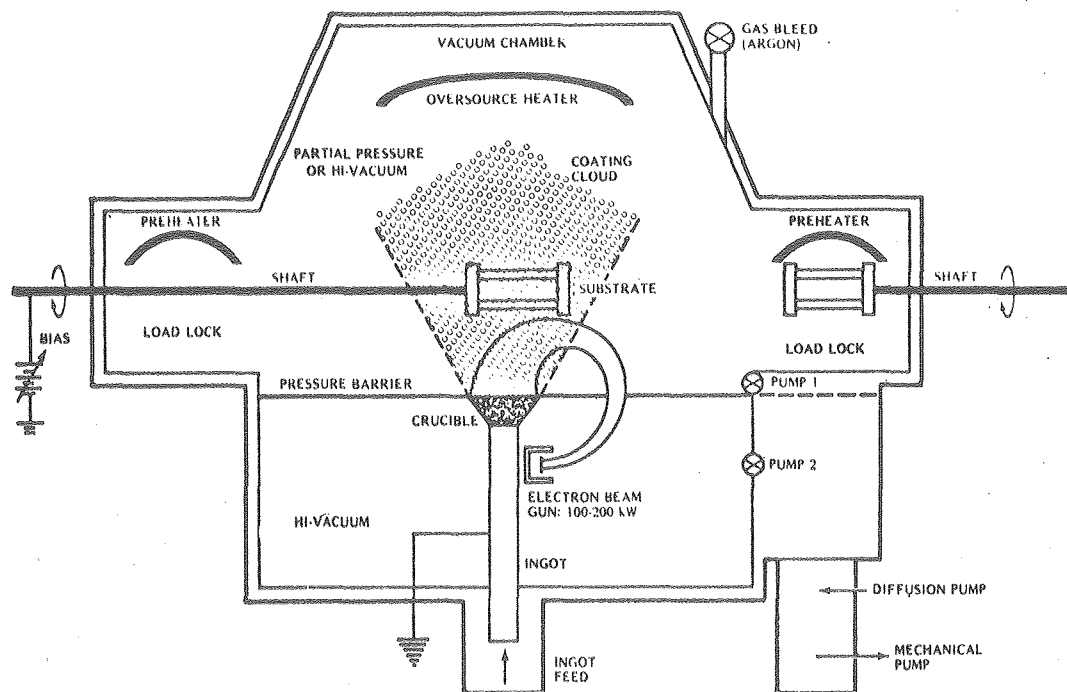
Substrate Composition and Process Limited
Substrate Structure Limited
Limited Low Temperature Ductility
Limited Active Element Effect

Fig. 3. Microstructure of an inward type, three zone aluminide coating on a nickel base superalloy and advantages and limitations of the process. Note preferential oxidation of substrate carbides entrapped in outer zone.



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Fig. 4. Microstructure of EB-PVD applied CoCrAlY Coating showing minimum zone of coating-substrate interdiffusion.



SCHEMATIC OF 200 kW COATER WITH GAS SCATTERING AND BIAS CAPABILITIES

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Fig. 5. Schematic representation of a Two Load Lock EB-PVD Airfoil Coater showing relative location of key components and operations. Provisions for gas bleed and substrate biasing are also shown if required for 'ion plating'

